



Texas Center for Superconductivity and Advanced Materials
University of Houston
NASA Commercial Space Center

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Solar Cell Fabrication on the Moon form Lunar Resources

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In-Space Fabrication and Repair Workshop



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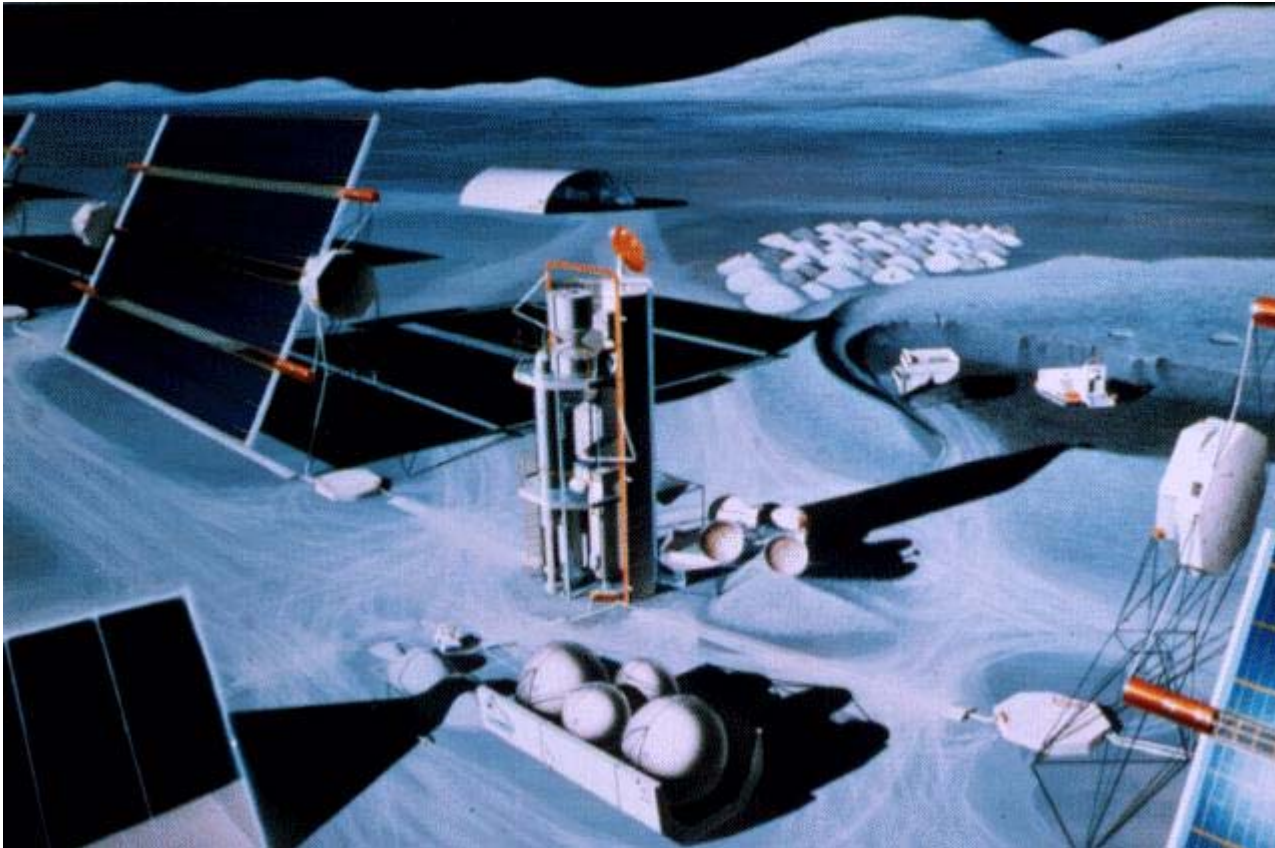
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Lunar Base



Lunar Power Requirements

- Initial : 100kW to 1 MW
- Non-Nuclear/ Non-Mechanical
- Solar Cells
 - Current technology: 300 W to 500 W/kg
 - From 300 to 3000kg to transport lightweight cells
 - High costs (~\$5B)

⇒ **WHAT DO WE DO ?**



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Living off the Land – Do This in Space :
In-Situ Resource Utilization (ISRU)

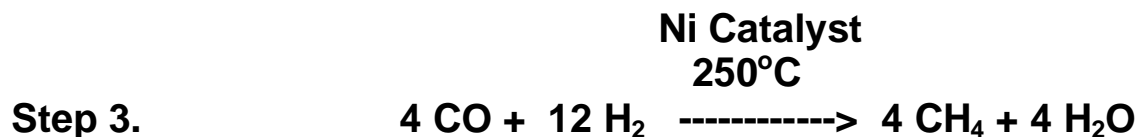
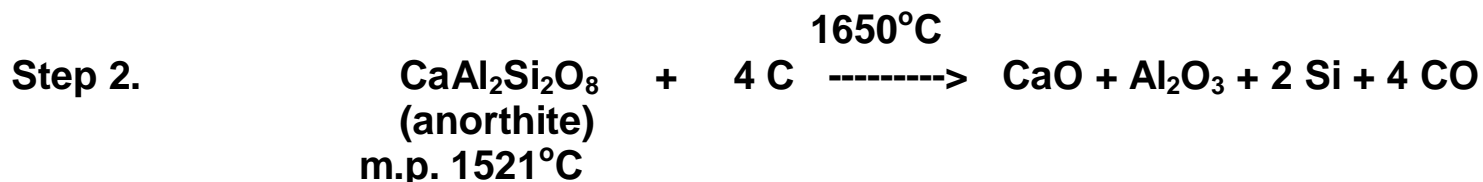


Fabrication of Solar Cells on the Surface of the Moon from Lunar Regolith

- **Moon's Surface is an Ultra-High Vacuum**
 - $\sim 10^{-10}$ Torr (day)
 - Use vacuum evaporation to make thin film solar cells
- **Elements Required for Silicon-based Thin Film Solar Cells are Present on the Moon**
 - Silicon
 - Iron
 - Titanium Oxide
 - Calcium
 - Aluminum



Carbothermal Reduction of Anorthite



⇒ Closed cyclic process yielding both OXYGEN and SILICON:





Ilmenite Reduction (Hydrogen or Carbon)

- $\text{FeTiO}_3 + \text{H}_2 \longrightarrow \text{Fe} + \text{TiO}_2 + \text{H}_2\text{O}$
- $\text{FeTiO}_3 + \text{C} \longrightarrow \text{Fe} + \text{TiO}_2 + \text{CO}$
- $3\text{FeTiO}_3 + \text{CH}_4 \longrightarrow 3\text{Fe} + 3\text{TiO}_2 + 2\text{H}_2\text{O} + \text{CO}$

⇒ Yields Iron for Interconnect and TiO_2 for Antireflect



Have All of the Components for Thin Film Solar Cell Deposition on the Surface of the Moon

- Vacuum
- Raw Materials
- Energy



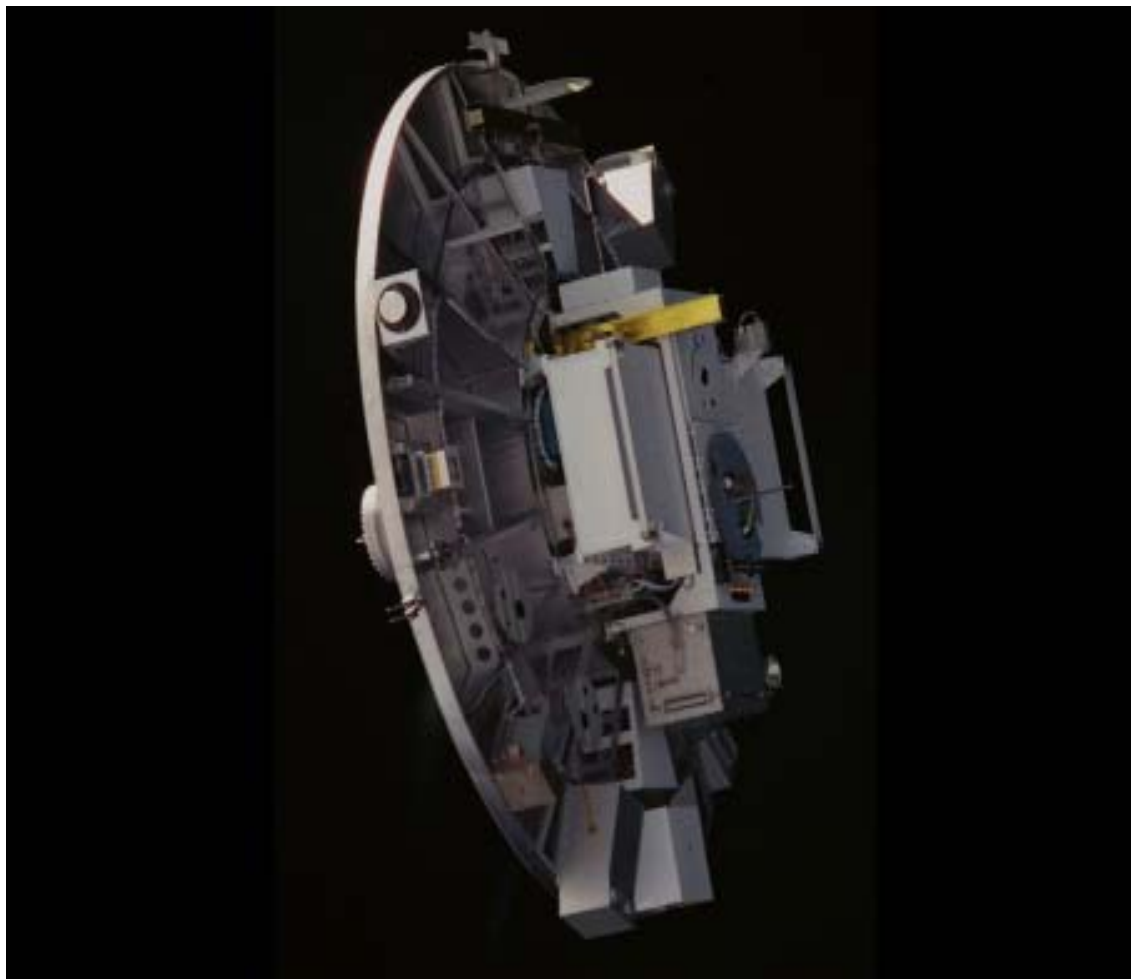
Vacuum Deposition of Thin Film Semiconductors in Space

- **Automated Thin Film Deposition in Space**
 - **Wake Shield Facility**
 - . Flown three times on Shuttle
 - . Grow thin film semiconductors in the ultra-vacuum of space
 - . Fabricate p-n junctions



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Wake Shield Facility in free flight -STS-80



Vacuum Deposition of Thin Film Silicon Solar Cells on the Moon

(In-Space Fabrication)

- **Automated Thin Film Deposition on the Surface of the Moon**
 - **Prepare substrate**
 - **Deposit bottom electrode**
 - **Fabricate p-n junction**
 - **Deposit top patterned electrode**
 - **Deposit antireflection layer**
 - **Interconnect individual cells**

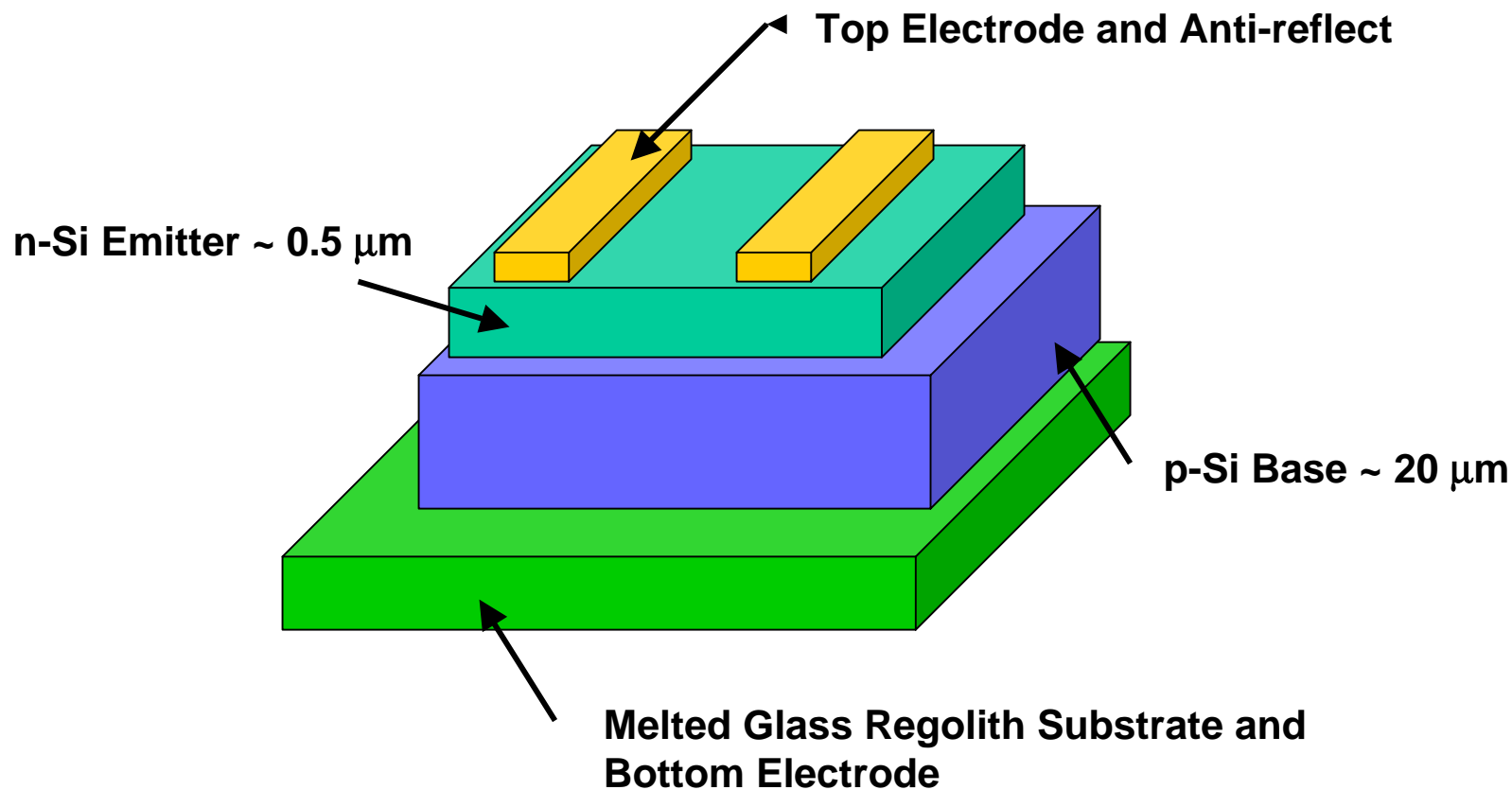


Fabrication of Solar Cells on the Surface of the Moon from Lunar Regolith

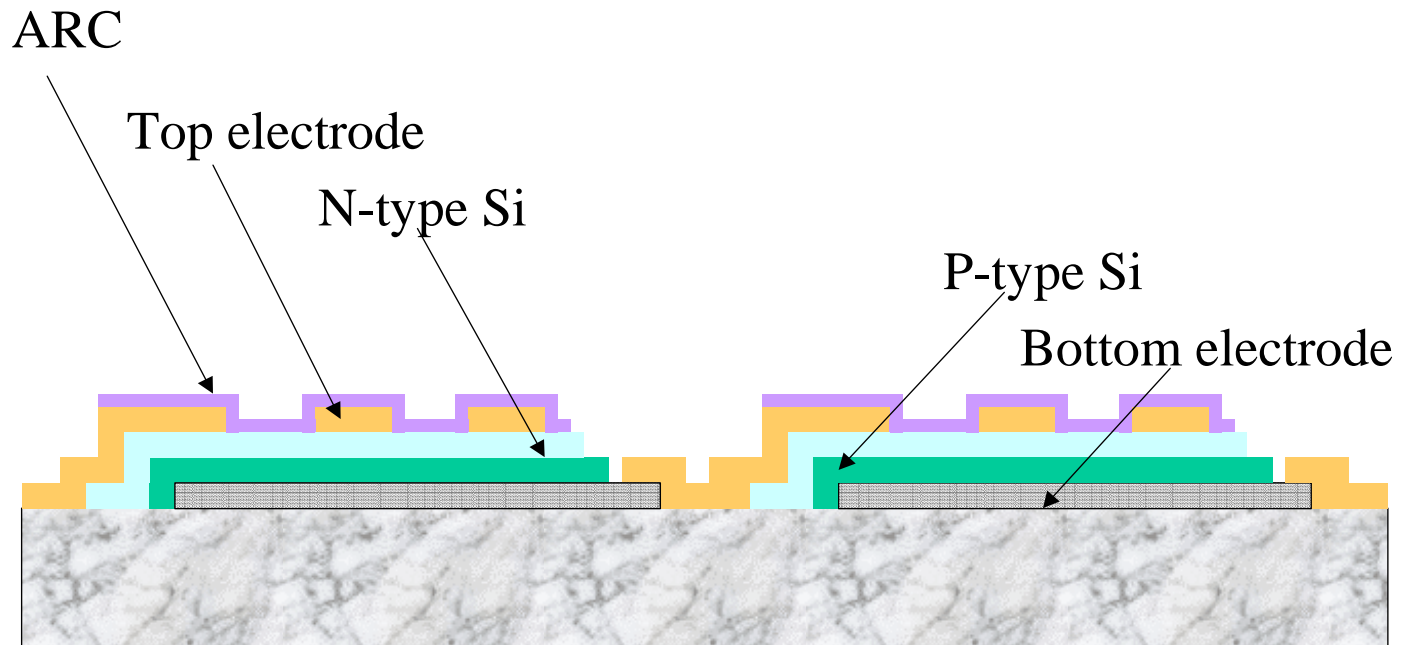
- **Fabrication of Silicon Solar Cells**
 - **Use lunar materials (Si, Fe, TiO₂, etc.)**
 - **Lunar 'glass' substrate - melt regolith by solar heat**
 - **Deposit polycrystalline silicon solar cells by solar evaporation**
 - **Interconnect solar cells serially for ~100V**
 - **Do cell fabrication robotically**



Lunar Silicon Solar Cell

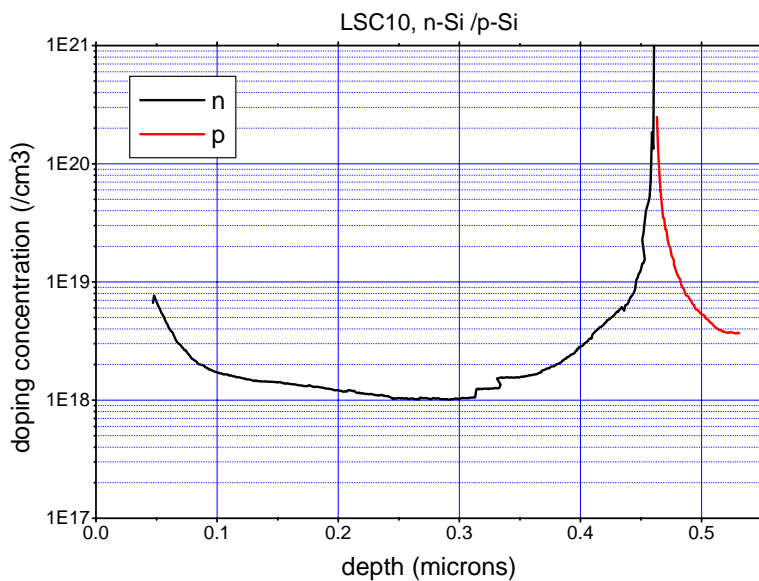


- **Lunar Solar Cell Interconnection**
 - **Stair-step interconnection**
 - **Serial connections for ~ 100V**
 - **Cell groups fabricated for ~ 10A**





Development of Si Solar Cell on Melted Regolith Substrate



**Si (n/p junction)/Al deposited on lunar
regolith substrate**



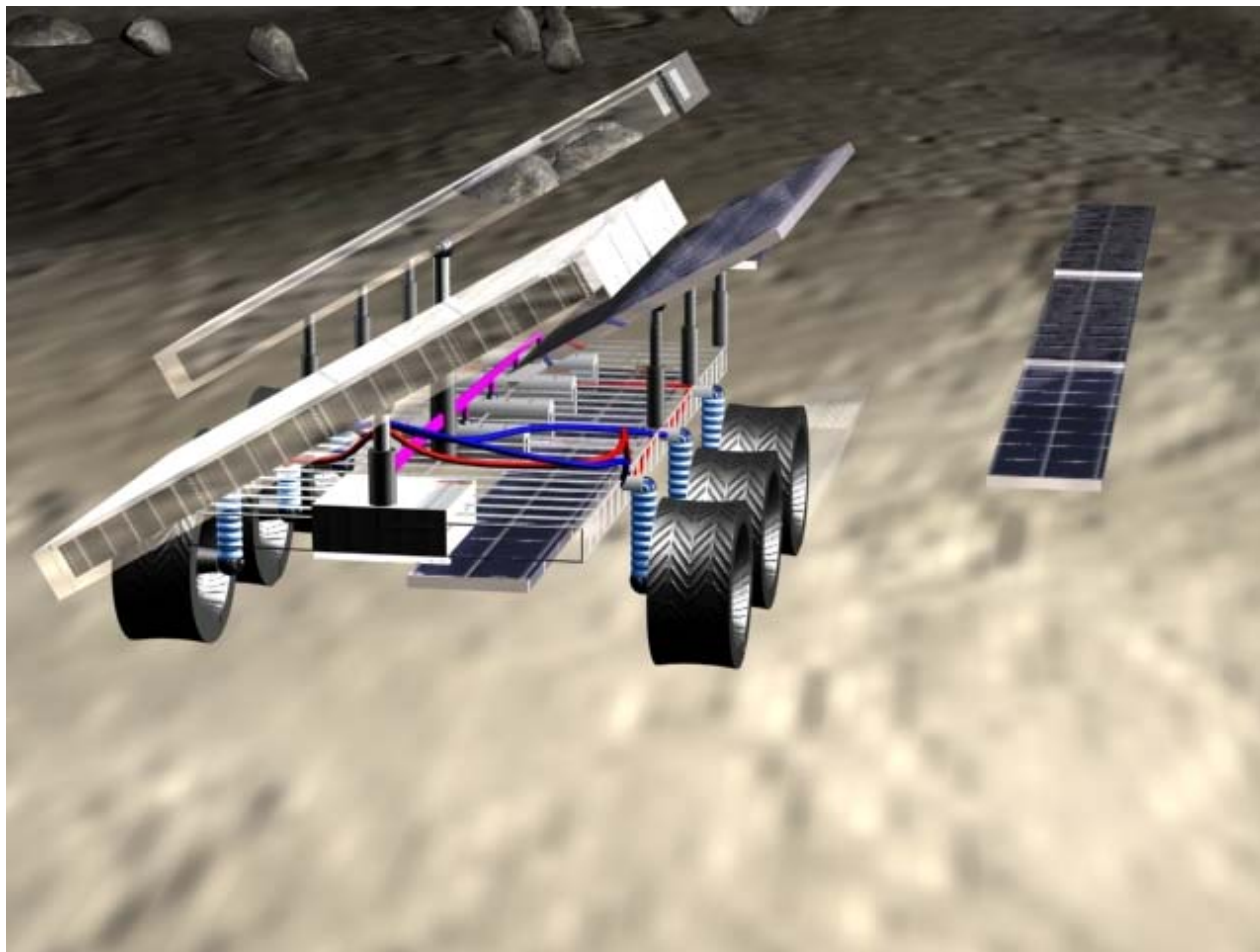
Fabrication of Solar Cells on the Surface of the Moon from Lunar Regolith

- **Mechanized Solar Cell Growth Facility - Crawler**
 - ~ 150 - 200 kg
 - Multiple parabolic trough solar collectors - slow tracking
 - Solar panels for power
 - Continuous lay-out of cells on lunar surface
 - East-west motion
 - Remotely controlled



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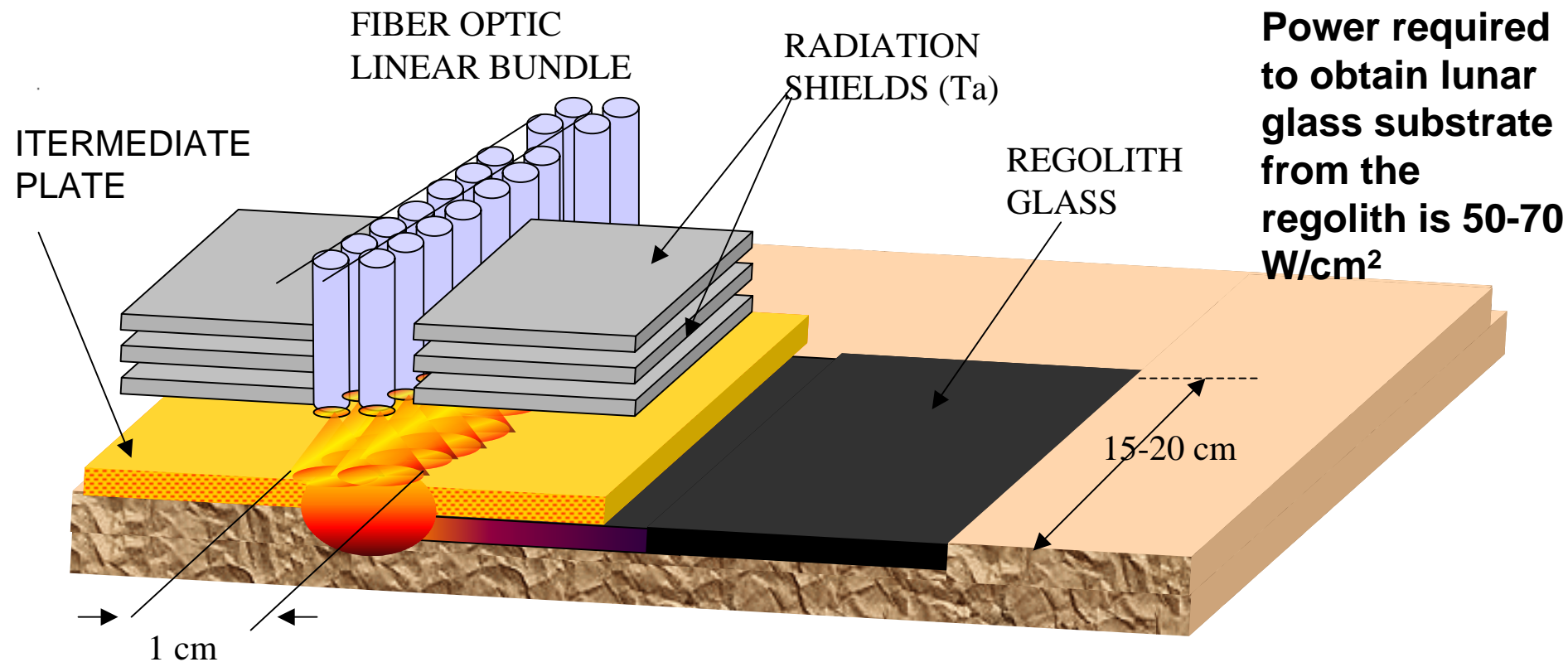
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Mechanized Solar Cell Growth Facility - Crawler



Solar Thermal Lunar Regolith Melting





Fabrication of Solar Cells on the Surface of the Moon from Lunar Regolith

- 1 m²/hr
- Fabricate ~ 65W/hr @ 5% and AMO (~1300 W/m²)
- Assume 35% uptime (~3060 hrs/yr)
- Fabricate ~200kW/yr capacity
- Require ~ 180kg of raw materials
- Continuous Cell Replacement – Self Replicating System
 - Assume limited cell lifetime
 - . Radiation damage
 - . Particle damage



Production of Solar Cells on the Surface of the Moon from Lunar Regolith

- **Ultra-high Vacuum on Lunar Surface Allows for Direct Thin Film Solar Cell Production**
 - **Less Mass to the Moon**
 - **Lunar Resources can be Utilized for Cell Production**
 - **Trade-off Cell Efficiency with Quantity**
 - **Multiple Facilities can be Utilized**
 - **Move to Industrial Scale Power Generation and Power Grid on the Moon**
- . 10 Rovers \Rightarrow from 2 to 4 MW/year
- . (Lunar Lighting & Power - LL&P)



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